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Measurement of various properties of Southern pine and aspen as function of heat treatment

Cagatay Tasdemir, Salim Hiziroglu *

Natural Resource Ecology and Management, Oklahoma State University, Stillwater, OK 74078-6013, USA

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ABSTRACT

The objective of this study was to investigate the influence of heat treatment parameters, namely temperature and exposure time on surface roughness, shear strength, hardness and density of Southern pine (*Pinus echinata*) and aspen (*Populus grandidentata*) samples. The specimens were exposed to two different temperature levels of 120–200 °C for time spans of 2–8 h. A stylus type portable profilometer was employed to evaluate the surface characteristics of the samples by taking measurements across the grain orientation. Average roughness (R_a), mean peak-to-valley height (R_z) and maximum roughness (R_{max}) were used to evaluate surface roughness of the samples exposed to various heat treatment schedules. Comten testing unit was also used to determine shear strength and Janka hardness of the control and heat treated specimens. Based on the results of this study Southern pine samples had more enhanced surface quality but lower hardness values than those of aspen specimens with increased temperature and time of heat treatment schedules. It was found that heat treatment adversely affected hardness and shear strength properties of all types of samples. Reduction in shear strength values of Southern pine and aspen samples ranged from 23.31% to 68.59% and from 4.67% to 48.55%, respectively as compared to those of control samples. It appears that influence of heat treatment on all properties of the samples was more pronounced with increasing temperature and exposure time.

1. Introduction

Southern pine (*Pinus echinata*) can be found in large area from Southern New York to Northern Florida as well as within Texas and Oklahoma. Southern pine lumber is produced principally in the Southern and South Atlantic States including Georgia, Alabama, North Carolina, Arkansas and Louisiana [1]. Sapwood of Southern pine is yellowish white and heartwood is reddish brown which is also usually wide in second-growth stands [1]. The heartwood begins to form when the tree is about twenty years old. In old, slow growth trees, sapwood may be only from 2 to 5 cm wide. All species of Southern pine have moderately high shrinkage characteristics but they are dimensionally stable when proper drying processes are applied to them. Southern pines with higher density and mechanical properties are extensively used for construction of warehouses, bridges and docks. Lumber of lower density and strength is used for building material, such as interior woodwork, sheathing and subflooring. It can be used for railroad crossties, piles, poles, mine timbers and exterior decking when it is treated with preservatives. The manufacture of structural-grade plywood is another major industry using Southern pine as raw material [1].

Aspen is a common name of big-tooth (*Populus grandidentata*) and quaking (*Populus tremuloides*) species. Aspen lumber is produced principally in the Northeastern and Lake States, with limited production in the Rocky Mountain States. The heartwood of aspen is grayish white to light grayish brown. The sapwood has lighter color and generally merges gradually into the heartwood without being clear distinction. Aspen wood is usually straight

* Corresponding author. Tel.: +1 405 744 5445.
E-mail addresses: cagatay.tasdemir@okstate.edu (C. Tasdemir), salim.hiziroglu@okstate.edu (S. Hiziroglu).

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grained with a fine, uniform texture. The wood of aspen is lightweight and soft. It is low in strength, moderately stiff, and low in resistance to shock with relatively high shrinkage. Aspen is mainly harvested for production of lumber, pallets, boxes and crating, pulp-wood, particleboard, and veneer. Aspen is also one of the most preferred raw material to produce oriented strandboard [1].

Heat treatment is one of the processes used to modify the properties of wood. This technique has been developed in Europe during the early 1990s [2–4]. Recent efforts on thermal treatment of wood have led to the development of several treatment processes introduced to the European market. Various companies in Holland and France have been producing commercially heat treated wood products [2–4]. Based on the results of some of the previous studies, it was found that heat treated wood becomes brittle, hardness and strength characteristics of the samples are adversely affected by decreasing range from 10% to 30%. Therefore in general heat treated wood would not be an ideal product where high strength properties for constructional applications are desired [4–6].

The temperature and exposure time in a typical heat treatment process range from 120 to 250 °C and from 15 min to 24 h, respectively depending on types of the process, species, sample size, moisture content of the sample and the desired target mechanical properties as well as resistance to biological attack and dimensional stability of the final product [4,7]. It is a fact that wood treated with high temperature has less hygroscopicity than natural wood. Heating wood permanently changes its several chemical and physical properties. Such change is mainly caused by thermic degradation of hemicelluloses. In other words, heat treatment of wood is combined by deformation of the lignin–polysaccharide complex by organic acids release from hemicelluloses in the cell wall [3,4].

In one of the past investigations, spruce samples were exposed to temperature levels of 120 °C–200 °C for 24 h [8]. It was found that the specimens had 15.5% weight loss [8,9]. In another study, redbud maple wood was exposed to temperature levels of 120 °C, 150 °C and 180 °C for time spans ranging from 2 h to 10 h [3]. The results showed that all mechanical properties including modulus of elasticity (MOE), modulus of rupture (MOR), Janka hardness and compression strength parallel to grain of the specimens decreased with increasing temperature and exposure time [3]. It was found that red oak samples exposed to 180 °C for 6 h had 14.6 N/mm^2 shear strength value which is 29% lower than that of the control samples in another heat treatment work [6].

It is a well-known fact that both species are widely used for different applications in the manufacture of value-added products including composite panels such as oriented strandboard, particleboard and plywood. It is also very important to produce dimensionally stable panel products for an effective utilization. Therefore, it is expected that applying proper heat treatment schedule to these species could result in enhanced shrinkage and swelling of the final product which can be used under different environmental conditions. Such statement was added in Section 1of the manuscript.

Although both basic physical and mechanical properties of Southern pine and aspen were investigated in detail, there is limited information on surface quality and shear strength properties of wood from these species as function of heat treatment. Therefore, the objective of this work was to determine effect of heat treatment on surface roughness, shear strength, hardness and density properties of samples from Southern pine and aspen. Based on the findings of this experimental work it is expected that heat treatment would be considered as alternative treatment method to enhance properties of these species, so that such species can be used more effectively and efficiently under the environmental condition without having any substantial problems.

2. Materials and methods

Two species were used in this study, namely Southern pine (*P. echinata*), aspen (*P. grandidentata*) were supplied by a local sawmill in Oklahoma. A total of 100 defect free samples with dimensions of 20 mm by 37 mm by 55 mm were prepared from each species. Dimensions of each sample were measured and they were weighted at accuracy of 0.01 mm and 0.01 g, respectively. Samples for each species were equally divided five conditions including a set of non-treated control samples while the other sets were exposed to heat treatment of two temperatures, 120 °C and 200 °C for 2 h and 8 h in a laboratory oven.

The density, roughness, shear strength and hardness characteristics of the samples were evaluated. Surface roughness for treated and control samples were measured using a portable stylus type profilometer Hommel T-500 unit which has a skid type diamond stylus with a 5 μm radius and 90° of tip angle [4]. Three well accepted roughness parameters, average roughness (R_a), maximum roughness (R_{max}) and mean-peak-height (R_z) calculated from digital information from the surface of each sample were used to evaluate their surface quality [10]. Five measurements were taken from mid-section of the surface of control and heat treated samples across the grain orientation using 15 mm tracing length. Figs. 1 and 2 illustrate typical surface roughness profiles of the specimens.

For shear strength experiment, polyvinyl acetate (PVAc) was used as adhesive applied on the both surfaces of each shear pair by brushing at a spread rate of 120 g/m^2. After adhesive application, the specimens were compressed together using a light pressure of 40.8 kg/cm^2 for 2 min and then they were left in room condition for 24 h. The shear strength of the samples was determined on a Comten testing unit equipped with a load cell having capacity of 1000 kg. The crosshead speed of machine during testing was 4 mm/min. Fig. 3 shows Comten testing system used in this work. Same testing unit having a steel sphere with 11.2 mm diameter was also employed for hardness measurement of the samples. Steel sphere was embedded into the sample in perpendicular to the grain direction to determine hardness values of each specimen.

The effect of heat treatment on wood anatomical structure was also investigated by using scanning electron